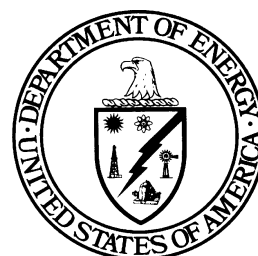


Mobilization, Extraction, and Removal of Radionuclides

Subsurface Contaminants Focus Area



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Mobilization, Extraction, and Removal of Radionuclides

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Subsurface Contaminants Focus Area

Demonstrated at
Fernald Environmental Management Project
Cincinnati, Ohio

INNOVATIVE TECHNOLOGY

Summary Report

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine whether a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at <http://ost.em.doe.gov> under "Publications."

TABLE OF CONTENTS

1. SUMMARY	page 1
2. TECHNOLOGY DESCRIPTION	page 5
3. PERFORMANCE	page 8
4. TECHNOLOGY APPLICABILITY AND ALTERNATIVES	page 15
5. COST	page 16
6. REGULATORY AND POLICY ISSUES	page 19
7. LESSONS LEARNED	page 20

APPENDICES

A. REFERENCES	page 22
B. BASELINE REMEDIAL STRATEGY MODELING	page 23
C. DEMONSTRATION PLAN DETAILS	page 28

SECTION 1 SUMMARY

Technology Summary

Problem

Groundwater contamination is a common problem at both private and government sites due to past manufacturing practices. Because of the unique mission of the U.S. Department of Energy (DOE), some DOE sites have groundwater contaminated with uranium and other radionuclides. These contaminants in the groundwater are often laterally dispersed over large areas and located vertically at depths up to hundreds of feet below ground surface, making aquifer restoration a difficult problem. The baseline technology of pump and treat will be very expensive over the extended life-cycles of these projects, predicted to be in excess of 30 to 200 years.

At the Fernald Environmental Management Project (FEMP), near Cincinnati Ohio, approximately 220 acres of the Great Miami Aquifer have become contaminated with uranium at concentrations greater than 20 µg/L as a result of nuclear weapons-production operations. The approved aquifer remediation strategy, that of pumping the groundwater and treating at the surface (the Record of Decision [ROD] for Operable Unit 5 [OU5]), was estimated to take approximately 27 years.

How It Works

Re-injection technology, as an enhancement to pump and treat, can accelerate the remediation of a groundwater plume by increasing the rate of aquifer flushing and by providing a hydraulic barrier to mitigate downgradient contaminant migration (Figure 1). Aquifer flushing facilitates the desorption of the metals and radionuclides from the aquifer matrix into the groundwater, making the contaminants more available for removal by pumping. Re-injection systems for aquifer flushing consist of extraction wells,

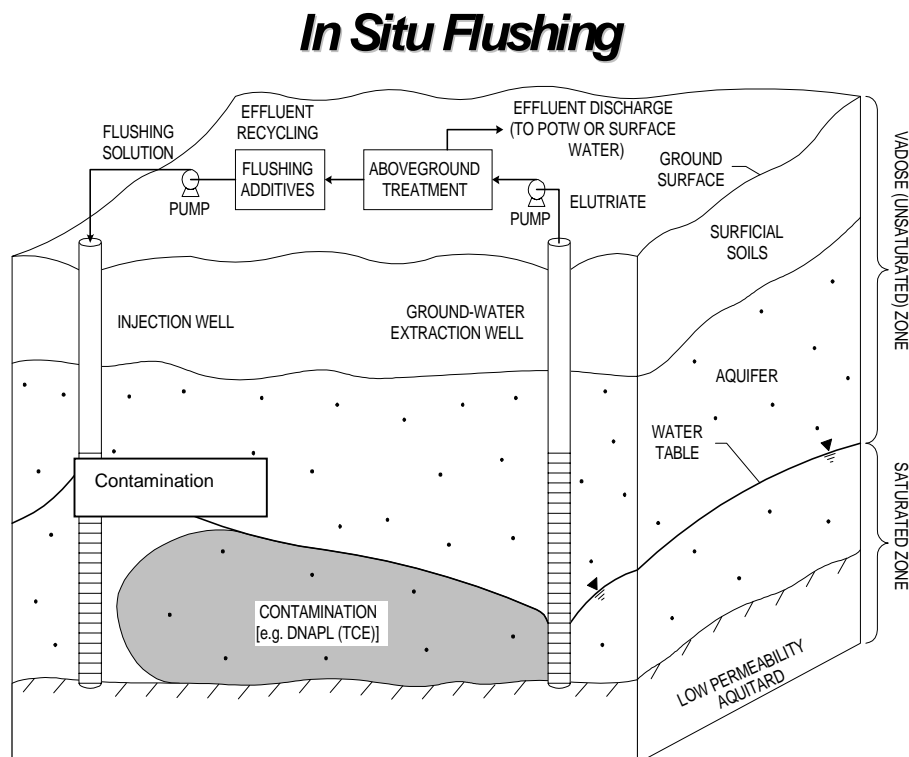


Figure 1. Schematic of re-injection technology.

above-ground treatment, and injection wells. Groundwater is extracted from the aquifer, treated to acceptable limits, and then re-injected into the aquifer to:

- control contaminant migration;
- increase the number of aquifer pore volumes flushed with "clean" water in a given time; and
- minimize pumping-related drawdown.

Re-injection systems can be further enhanced by injecting various treatment agents (bionutrients, chemical oxidant or reductant, complexation agent, air, steam) to treat a variety of contaminants of concern, by maximizing pore-volume flushing. At the FEMP, addition of treatment agents was determined to add an unnecessary risk, given the predicted performance using treated groundwater only.

Potential Markets

Re-injection technology as an enhancement to pump and treat systems can be used in any aquifer with sufficient permeability to sustain injection of potentially large volumes of groundwater and/or treatment agents with compatible chemistry; this allows for continuous, cost-effective operation of the injection wells.

Advantages Over Baseline

Advantages of groundwater re-injection systems may include:

- shortening the duration required to achieve aquifer restoration goals;
- minimizing drawdown impacts at neighboring properties and in the target cleanup zones by returning extracted water back into the aquifer following treatment; and
- providing a hydraulic barrier to minimize the potential for further off-property contaminant migration.

Limitations of re-injection systems include the following.

- Extraction rates are dependent upon site-specific hydrogeologic conditions;
- Injection rates and injectate quality are dependent on site-specific hydrogeologic and geochemical conditions;
- Injection and extraction well spacings are dependent upon site-specific hydrologic conditions; and
- Strongly sorbed contaminants may not respond to such treatment.

Demonstration Summary

The Mobilization, Extraction, and Removal of Radionuclides (MERR) demonstration was conducted from September 2, 1998 to September 2, 1999 along the southern property boundary of the FEMP (Figure 2). Modeling simulations of the baseline OU5 remedy indicated aquifer restoration in 27 years using 28 conventional extraction wells with system-wide pumping rates totaling ~4000 gpm. Modeling simulations that included the addition of an injection enhancement and an optimized extraction strategy (early source removal, accelerated start-date, and refinements in understanding the uranium desorption process) indicated that aquifer remediation could be accelerated to 10 years (Appendix B).

The full-scale re-injection system at the FEMP was designed using modeling simulations to include:

- thirty-seven extraction and ten injection wells grouped into seven modules (including the demonstration module) located in four distinct areas or zones of aquifer contamination;
- design of each module to remediate a specific area or "hotspot" of the aquifer; and
- installation and operation of each module using a phased approach as surface remediation activities are completed and access becomes available.

The principal contaminant of concern is total uranium, which has been reported as high as 490 ug/L in the demonstration area; The Great Miami Aquifer is an unconfined, anisotropic, and heterogeneous buried valley sand-and-gravel aquifer, ranging up to 200 feet in thickness near the FEMP. A thin veneer of

younger glacial-till deposits (mostly clay) overlay the sand and gravel unit, which in turn overlays bedrock at approximately 200 feet in depth.

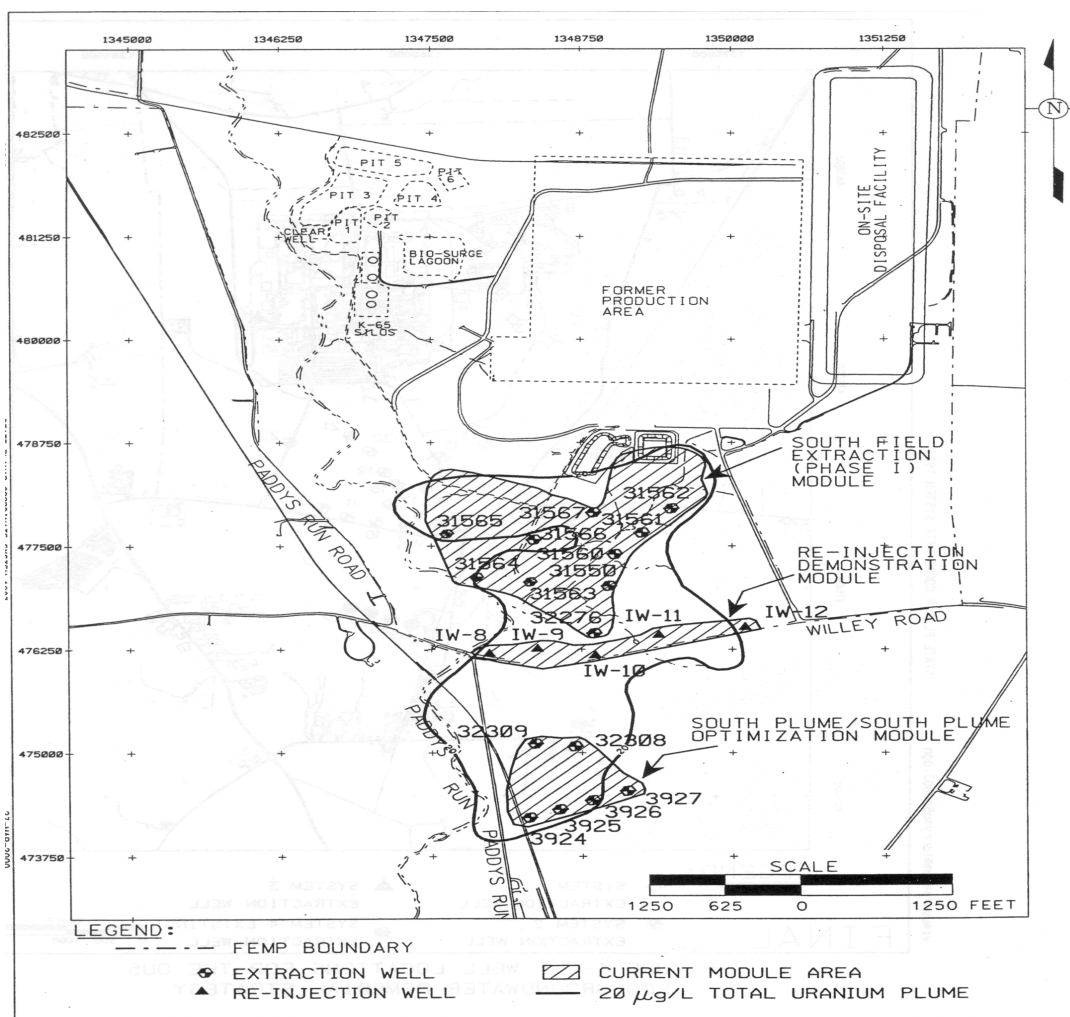


Figure 2. Map of MERR demonstration injection and extraction wells.

During the MERR demonstration, groundwater was:

- extracted from a total of 15 wells located both upgradient (to the north) and downgradient (to the south) of the injection wells;
- treated at the FEMP Advanced Waste Water Treatment (AWWT) Expansion Facility to remove uranium; and
- re-injected (1000 gpm) into the aquifer near the southern fenceline.

Key Results

- During the one-year demonstration, ~455 million gallons of treated groundwater were re-injected into the Great Miami Aquifer.
- Capture of the 20 µg/L uranium (final remediation level [FRL]) plume was maintained during the demonstration.
- Injection did not push the base of the 20 µg/L uranium plume into deeper regions of the aquifer (i.e., the thickness of the uranium plume remained relatively unchanged or was reduced during one year of extraction and re-injection).
- The re-injection system effectively flushed contamination south of the injection wells, but the narrow zone of influence resulted in ineffective flushing between the injection wells (i.e., the decrease in

uranium concentrations immediately south of the injection wells was much greater than the uranium decrease recorded between the wells).

- A stagnation zone, which provided a hydraulic barrier to prevent further southward migration of on-property contamination, was created at the southern FEMP property boundary, where the injection wells were located.
- Re-injection had a very minor impact on the chemistry of the groundwater in the Great Miami Aquifer.
- Continued use of re-injection is predicted to save \$14.3 million dollars (net present value, assumes that the re-injection will reduce the OU5 ROD approved aquifer remediation by seven years).
- The AWWT Expansion Facility was capable of providing a reliable source of water protective of the aquifer for re-injection.
- Maintenance costs for the injection wells appear reasonable; treatments used to address plugging in the injection wells appeared adequate.

The demonstration was sponsored by the DOE's Office of Science and Technology Subsurface Contaminants Focus Area. Team members included the following:

- DOE Fernald and Fluor Fernald, Inc. – site operations, design, and hydrogeology support;
- MSE-Western Energy Technology Office – hydrogeology support and coordination of industry partnership;
- Rio-Algom Environmental Services Inc. – aquifer geochemistry support, injection well maintenance support, and re-injection systems operation support; and
- In-Situ Inc. – groundwater monitoring instrumentation support.

Ohio EPA re-injection guidelines were used as a design criterion for the re-injection system. Injectate was required to meet the FRL of 20 µg/L total uranium. Re-injection systems have been widely used in the petroleum and solution mining industries for numerous years. Commercial vendors are readily available for design and installation of such systems.

Contacts

Technical

Rob Janke, DOE-FEMP
513-648-3124

Dave Brettschneider, Fluor Fernald
513-648-5814

Terrall Putnam, Fluor Fernald
513-648-6363, Terrall.Putnam@fernald.gov.

Management

Lynton Yarbrough, Subsurface Contaminants Focus Area Product Line Manager, DOE Albuquerque
505-845-5520

Other

All published Innovative Technology Summary Reports are available on the OST Web site at <http://ost.em.doe.gov> under "Publications." The Technology Management System (TMS), also available through the OST Web site, provides information about OST programs, technologies, and problems. The OST/TMS ID for Mobilization, Extraction, and Removal of Radionuclides is 157.

SECTION 2 TECHNOLOGY DESCRIPTION

Overall Process Definition

The overall goal of the MERR demonstration was to assess the performance and cost of a re-injection system as an enhancement to the existing pump and treat system at the FEMP site (Figure 3). Factors affecting that decision include:

- operation and maintenance costs of the injection wells;
- effectiveness in shortening the remedy as predicted through modeling simulations;
- demonstration that the vertical and horizontal extent of the 20 µg/L uranium plume was not significantly expanded horizontally or vertically; and
- creation of a hydraulic barrier at the Southern FEMP property boundary to mitigate off-property contaminant migration.

Re-injection technology, as an enhancement to pump and treat systems, utilizes injection wells to increase the rate of aquifer treatment by flushing the target volume and/or by providing a hydraulic barrier to mitigate downgradient contaminant migration. Re-injection systems include both extraction and injection wells. Design and construction techniques for injection wells are of utmost importance, as they are much more likely to fail than extraction wells (Driscoll 1996).



Figure 3. Photograph of injection well-head at the FEMP.

Compared to groundwater extraction alone, simultaneous groundwater extraction and re-injection increases the pore-volume exchange rate within the aquifer by flushing the volume of interest while maintaining hydraulic control (capture). Increased pore-volume exchange rates enable increased contaminant mass-transfer rates from the aquifer matrix to the groundwater.

Key factors affecting re-injection system performance for aquifer flushing include:

- hydraulic characteristics and capacity of the aquifer (e.g., aquifer heterogeneity and anisotropy, maximum pumping and injection limits);
- geochemical processes that control the amount and rate of contaminant mass removal with each pore volume exchange;
- long-term performance of injection wells (e.g., deleterious effects of iron bacteria);
- well design and installation methods;
- source-area remediation schedule (e.g., duration of source loading and availability of access to the aquifer for extraction); and
- operation and maintenance of the system (e.g., capacity and efficiency of the surface treatment plant).

Re-injection systems for restoration of groundwater contaminated with metals and radionuclides are applicable at DOE sites where (1) sufficient aquifer permeability to facilitate groundwater flushing through extraction and injection wells exists, and (2) aquifer chemistry is compatible with re-injection, minimizing mineral precipitation that can cause well plugging.

System Operation

This demonstration included the following operations.

- Groundwater was pumped from the aquifer at a net rate of 3500 gpm.
- 2000 gpm of groundwater was sent to treatment, 1800 gpm was sent to the AWWT Expansion Facility (groundwater with uranium concentrations <20 ug/L was not sent to treatment).
- 1000 gpm of treated groundwater from the AWWT Expansion Facility was re-injected back into the aquifer for the demonstration.
- 2500 gpm of groundwater (treated and untreated) was discharged to the Great Miami River.

At an injection rate of 1000 gpm and a duration of one year, approximately 526 million gallons of water were anticipated to be injected into the aquifer during the demonstration. Each of five injection wells were operated continuously at 200 gpm. Flow to each injection well was programmed to automatically shut off should the water level rise to a predetermined level.

Injection-well efficiency (i.e., plugging) was monitored continuously. Water-level measurements, down-hole camera surveys, microbial sampling, and injectate quality analyses were used to evaluate plugging. Rehabilitation of a plugged injection well consisted of:

- addition of sodium hypochlorite solution to the well, surging the well briefly to get the chemical out into the gravel pack and surrounding formation, then allowing the chemical to work for 12 - 24 hours;
- swabbing and airlifting the well for approximately 90 minutes to remove the residual sodium hypochlorite reaction by-products and dead bacteria; and
- pumping out a minimum of five times the volume of standing water in the well or five times the volume of sodium hypochlorite solution added to the well, whichever is more.

The MERR demonstration involved the installation and construction of:

- five injection wells (Figure 4);
- nine monitoring wells;
- a 50,000-gallon surge tank;
- two 100-horsepower pumps;
- electrical service;
- ~5,000 feet of trenching and placement of HDPE piping;
- fabrication of injection-well downcomers to prevent cascading of water, which could cause air bubbles to be injected into the aquifer; and
- instrumentation and controls.

No special skills or training are required for operation of re-injection systems. However, routine maintenance of the injection wells and treatment of the groundwater are required.

Special secondary waste stream considerations involved the spent sodium hypochlorite used to treat well plugging. Secondary waste generation during well maintenance and sampling included purge water, contact wastes, and equipment decontamination solutions.

The primary operational concern for use of a re-injection system at the FEMP was how much and how often the injection wells would be inoperative due to plugging problems, the resulting costs needed to keep them operating, and operation of the groundwater treatment system.



Figure 4. Workers installing a 16" well casing in one of the injection wells.

SECTION 3

PERFORMANCE

Demonstration Plan

During the MERR demonstration, 1000 gpm of treated groundwater (injectate) from the AWWT Expansion Facility was re-injected into 5 wells at a rate of 200 gpm per well. The injection wells were utilized to:

- enhance aquifer flushing of contaminants;
- minimize pumping-related drawdown impacts at neighboring properties beyond the FEMP property;
- minimize excessive drawdown of water levels in the target cleanup zones by maintaining high water levels in the areas where re-injection is occurring; and
- provide a hydraulic barrier (stagnation point) at the FEMP's southern property boundary to minimize the potential for further off-property contaminant migration.

The overall goal of the MERR demonstration was to assess the performance and cost of a re-injection system as an enhancement to the existing pump and treat system at the FEMP site. Specific objectives were to:

- determine if a re-injection rate of 200 gpm per well could be sustained for a time period of one year;
- determine the operation and maintenance costs required for maintaining this injection rate for each well;
- determine if treatment of extracted groundwater could be maintained to provide a stable source of acceptable injectate;
- determine if the re-injection system would perform as modeled to maintain capture of the 20 µg/L uranium plume;
- determine if a hydraulic barrier could be produced and maintained at the southern boundary of the FEMP using the 200 gpm per well injection rate; and
- map actual hydraulic patterns and profiles to assess the extent of the influence of the system on aquifer flushing and the geometry of the water table as predicted by the groundwater model.

The key elements of the MERR demonstration at FEMP, as shown in Figure 2, included:

- the Injection Demonstration Module consisting of 5 injection wells located along the FEMP southern property boundary (well numbers IW-8, -9, -10, -11, and -12);
- the Phase I South Field Extraction System Module consisting of 10 extraction wells located upgradient of the re-injection wells (well numbers 13, 14, 15, 16, 17, 18, 19, 20, 21, and 22);
- the South Plume Optimization Module consisting of 2 extraction wells located downgradient of the injection wells (well numbers 1 and 3N);
- the South Plume Module consisting of 4 extraction wells located downgradient of the injection wells (well numbers 24, 25, 26, and 27); and
- the AWWT Expansion Facility with an increased groundwater treatment capacity.

Injection wells were installed using various completion methods, well diameters, and screen positions (Figure 5 and Appendix C). Four screens (IW-8, -9, -10, and -11) were located within the 20 ug/L total uranium plume and one screen (IW-12) was located outside the plume. The screen length was set at 15 ft to maximize the length of the screen but limit the depth of injection to the upper regions of the aquifer where the contaminant plume is located and where iron concentrations are lower. Water-level sensors

were installed, operated continuously, and monitored in each well by operators in the AWWT control room.

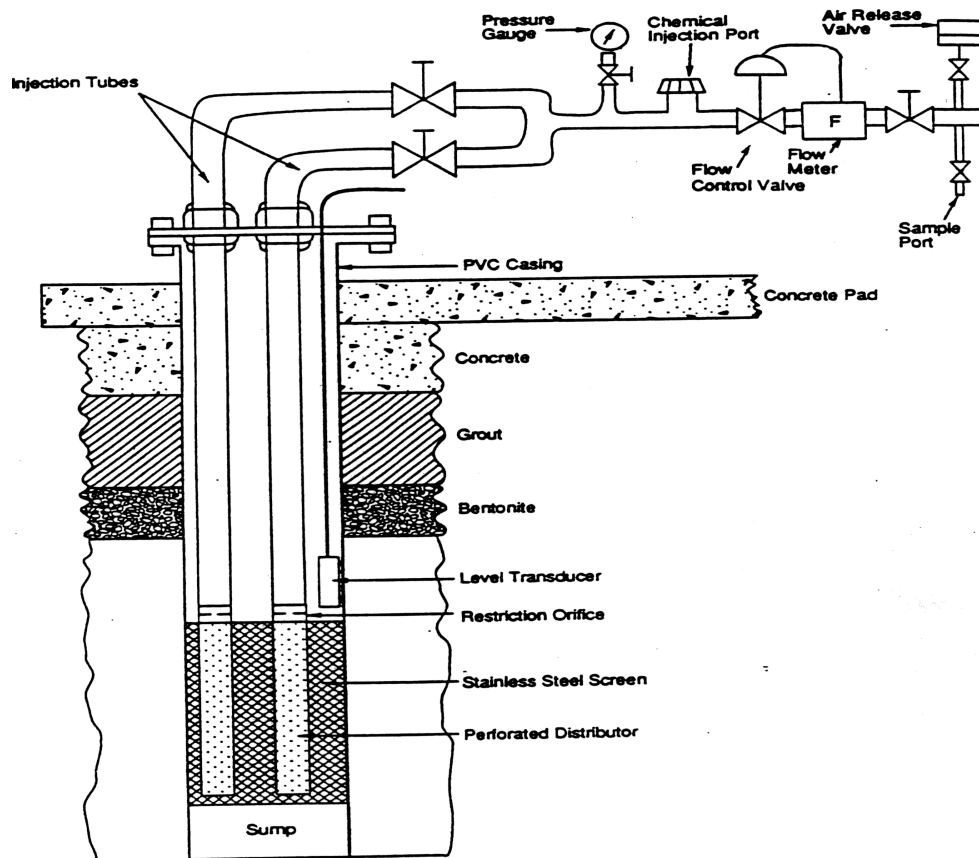


Figure 5. General design of injection wells.

This demonstration was limited to one year of operation within the southern portion of the plume.

Monitoring Aquifer Impacts

Impact on the aquifer remediation was evaluated through water-level and uranium-concentration data. Figure 6 is a map showing monitoring well locations.

- Water-level measurements were collected:
 - from 55 monitoring wells at varying frequencies
 - twice prior to start of re-injection (one week prior and one day prior);
 - weekly during the first month of operation (September 1998);
 - monthly during the remainder of the demonstration (October 1998 through August 1999);
 - and
 - from 159 locations quarterly in conjunction with the ongoing Integrated Environmental Monitoring Plan to evaluate regional trends.
- Uranium-concentration data were collected:
 - quarterly from 23 monitoring wells in closest proximity to the injection wells; and
 - six times from 7 direct-push sampling locations also located in close proximity to the injection wells.

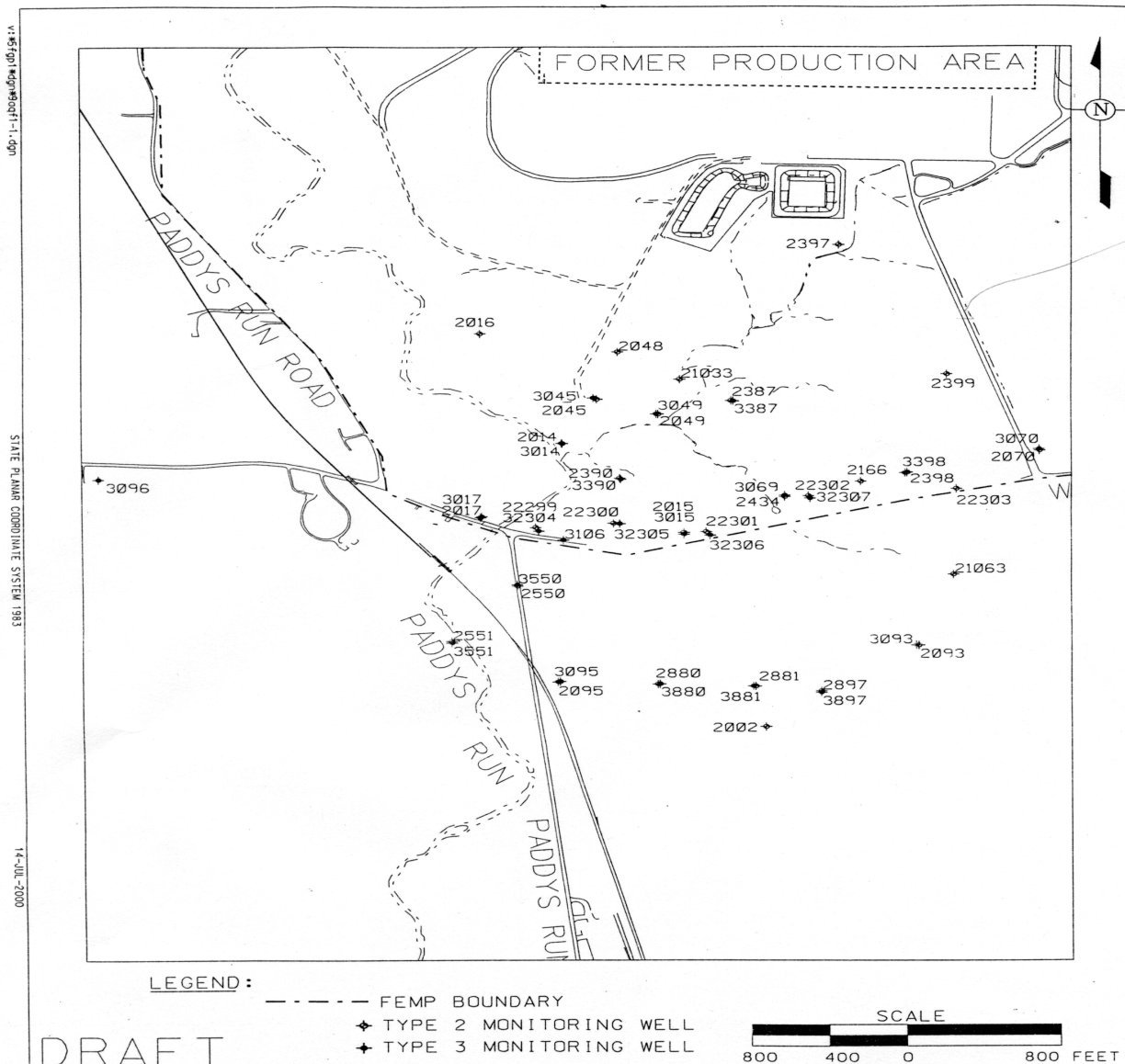


Figure 6. Map showing monitoring well locations.

Impact on the aquifer chemistry was evaluated through the following analytical measurements of groundwater samples:

- quarterly collection of groundwater samples from twenty-three groundwater monitoring wells within the demonstration area (samples were analyzed for major anions and cations, along with uranium);
- six rounds of groundwater samples from direct-push sampling locations (samples were analyzed for major anions and cations, along with uranium); and
- monthly monitoring of water temperature, pH, specific conductivity, oxygen, and Eh in 5 shallow and 4 deep observation wells utilizing a down-hole water-quality probe (*in situ* parameters).

Monitoring Re-injection System Performance

The following data were collected to evaluate if and why plugging was occurring:

- continuous groundwater-level monitoring with down-hole pressure transducers to determine if plugging resulting in resistance to flow could be measured as a rise in water level;

- quarterly down-hole camera surveys from within the injection wells to determine if any visible evidence of plugging could be seen;
- quarterly microbiological analysis of groundwater (using Biological Activity Reaction Test [BART] culture kits) from injection wells and nearby monitoring wells; and
- monthly monitoring the total suspended solids (TSS) of the water being injected.

Results

Quality of Injectate

An important objective of the demonstration was to determine if the groundwater could be reliably treated to meet re-injection requirements. During the 17 months of sampling, only four FRL exceedances were measured in the injectate grab samples (Table 1). Analysis of injectate grab samples indicated steadily

Table 1. Injectate FRL exceedances during the demonstration

Date	Constituent	FRL Value	Sample Result
10/23/98	Zinc	0.021 mg/l	0.0213 mg/l
4/8/99	Lead	0.015 mg/l	0.0191 mg/l
6/14/99	Bis(2-ethylhexyl)Phthalate	6 µg/l	8 µg/l
7/14/99	Uranium	20 µg/l	26.8 µg/l

increasing uranium concentrations from January 1999 (~0.1 µg/L) to August 1999 (~13 µg/L), then subsequently decreasing concentrations through November 1999 (0.1 µg/L) (Figure 7). This trend is attributed to the increasing degree of uranium saturation of the ion-exchange resin at the AWWT Expansion Facility, followed by regeneration of 3 vessels between August and November 1999. In addition, a series of random “spikes” or “peaks” of higher uranium concentrations, some of which exceeded 20 µg/L, were believed to have resulted from inadvertent valve leakage, which resulted in untreated or partially treated water bypassing one or more ion-exchange vessels and going directly to discharge.

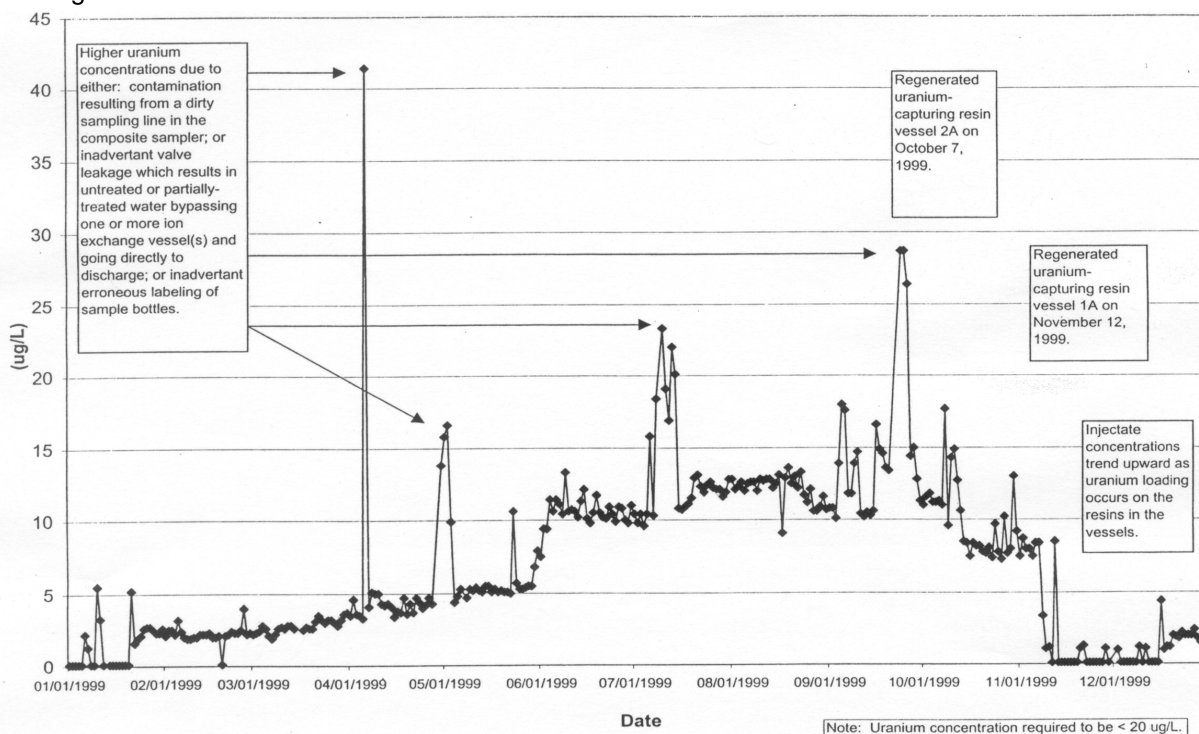


Figure 7. Uranium concentrations from the AWWT expansion system.

Water-level measurements demonstrated the overall lowering of the water table over the course of the demonstration was not as great as predicted by the model; aquifer yield is believed to be greater than predicted.

- The water-level increases due to groundwater re-injection were limited to the areas immediately surrounding the wells and were not evenly distributed (lower around injection wells IW-10, IW-11, and IW-12 than expected).
- Only two injection wells (IW-8 and IW-9) produced a water-level rise in the aquifer of greater than 0.5 feet, as predicted by the model.
- Following start-up of re-injection, only seven monitoring wells recorded an increase in water level as a result of re-injection.

Direct-push sampling indicated that re-injection was effective in flushing uranium immediately south of the injection wells, but not between the injection wells.

- Quarterly samples collected at 3 locations downgradient of the injection wells within the portion of the plume containing initial total uranium concentrations >400 ug/L indicated dramatic reductions in uranium concentrations (largest decreases in uranium concentrations were 82 µg/L and 118 µg/L) (Figure 8).

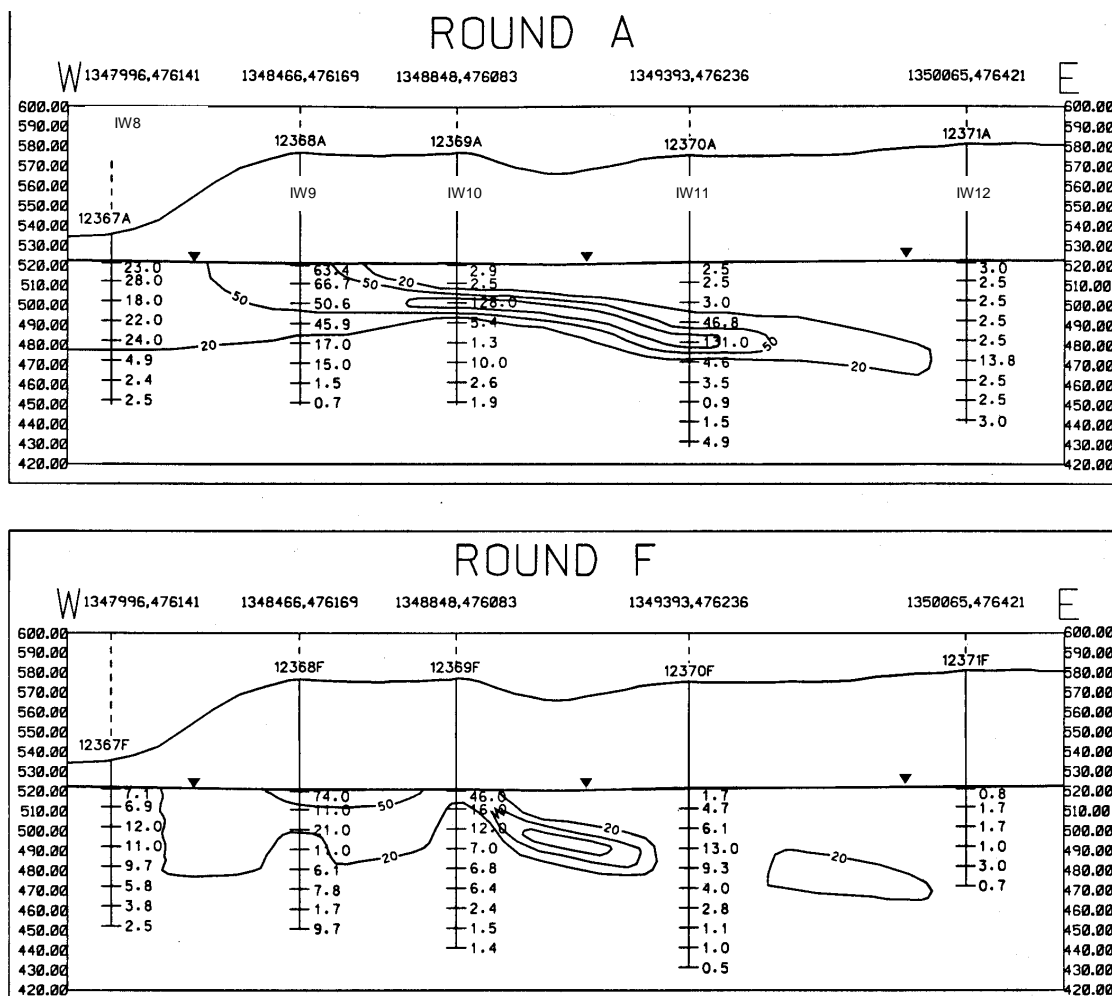


Figure 8. Uranium plume profiles from the 1st and 6th sampling rounds using direct-push sampling technology at locations adjacent to the injection wells, shown as vertical lines (Rounds A and F). IW 8 through IW 12 are shown from left to right.

- Quarterly samples collected at locations between the injection wells did not show similar reductions in uranium concentrations; the thickness of the uranium plume between the injection wells remained relatively unchanged after one year of re-injection.
- Measured average gradients north and south of the injection wells were very close to model predictions, indicating that water is being flushed at about the same rate as the model predicted (Appendix B).
- Flushing zones downgradient of the injection wells are expected to coalesce at some point to the south as they approach the South Plume Extraction Wells (perhaps further downgradient than the monitoring locations or after longer periods of re-injection [> 1 yr]). This plume interpretation is in agreement with modeled flow-path predictions that indicate narrow flow paths south of each injection well in the vicinity of the direct-push sampling locations.

Capture of the 20 $\mu\text{g/L}$ uranium plume was assessed by collecting water-level data, preparing water table maps, interpreting hydraulic capture zones, and then correlating the capture interpretations to the location of the uranium plume (Figure 8).

- Capture of the 20 $\mu\text{g/L}$ uranium-plume was maintained during the demonstration.
- Based on direct-push data, the base of the 20 $\mu\text{g/L}$ uranium plume was not displaced or expanded into deeper regions of the aquifer.
- The combined effect of pumping in the South Plume and South Field created a stagnation zone between the two pumping systems. This stagnation zone served as a hydraulic barrier to the southern flow of groundwater across the southern FEMP property boundary, preventing further off-site uranium migration.
- Comparison of the water-level measurements to the model simulations indicated that the influence of re-injection on raising water levels in the stagnation zone (enhancement of the hydraulic barrier) was not as great as was predicted and the overall water level rise in the aquifer was not evenly distributed across the re-injection area.

Major anion and cation concentration data document that the injection of treated groundwater had a very minor impact on the chemistry of the groundwater in the Great Miami Aquifer. The minor changes, which were observed near the injection wells (dissolved oxygen, sulfates, and chloride concentrations), are not expected to have a deleterious impact on contaminant migration or remedy performance.

Injection Well Performance

Plugging, defined as "the increasing resistance to flow", within the injection wells was a major concern at the start of the demonstration. While no indication of residual plugging was noticed during the year-long demonstration, some degree of residual plugging is anticipated if the system is operated for a number of years. The impact that residual plugging might have on future operational cost remains uncertain, but is expected to be manageable. Well-maintenance treatments were required on six occasions (Figure 9).

- The water-level rise in injection well IW-10 rose high enough to require treatment for plugging twice; the water level rise in injection well IW-8 rose high enough to require treatment for plugging four times. None of the other three injection wells (IW-9, IW-11 and IW-12) required treatment for plugging.
- Visual evidence of iron bacteria within the well, including the inner surface of the well screens was not confirmed in any of the camera surveys. Thus, plugging may be occurring outside the well screen and out of the view of the camera, perhaps at the interface between the filter pack and the natural formation.
- Groundwater samples from injection wells indicated aggressive growth of all three types of bacteria being tested for, regardless of when the samples were collected. No evident pattern was observed relating microbial population to well rehabilitation or inspection.

- The monthly grab samples all had measured TSS concentrations of less than 1 mg/L. However, suspended solids in the injection water at even these low concentrations could contribute to long-term plugging problems.



Figure 9. Workers performing maintenance on a well.

The cause for more frequent plugging of IW-8 as compared to the other four injection wells could be attributed to:

- its close proximity to Paddy's Run, perhaps recharging nutrients for bacterial growth;
- its shallow depth; the water table (~20 ft below ground surface [bgs]) is much shallower in IW-8 than in the other four wells (~ 60 ft bgs);
- its smaller diameter; IW-8 is an 8-inch diameter well, which has less surface area than a 12-inch or 16-inch diameter well; and
- an Eh change in the groundwater, resulting in the oxidation of Fe^{2+} to Fe^{3+} , thus forming iron oxyhydroxide particulate and increasing bacterial growth.

Overall Re-injection System Performance

The model simulation assumed injection of 1000 gpm of treated water with no downtime for well maintenance. During a one-year demonstration, this would equate to approximately 526 million gallons of groundwater injected. Actual operations resulted in the injection of approximately 455 million gallons of treated water or 86.5 % of the predicted volume. Based on these results, future injection is recommended to be increased to 1112 gpm (222 gpm/well), while assuming a 90 percent operation time.

Quarterly water-table maps show the capture zones and groundwater flow divides that existed during the demonstration. These capture zones and flow divides are generally in good agreement with modeled flow path predictions (Appendix B, Figure B-2), with the exception of the eastern portion of the area (east of IW-12).

Water-level data indicate that a stagnation zone was created between the two extraction modules, as was predicted by the groundwater model. The model simulation predicted a water-level rise of approximately 0.5 feet at each injection well; measurements indicated a rise of >0.5 feet at only two of the injection wells (IW-8 and IW-9) in the western portion of the demonstration area.

SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Competing Technologies

The baseline technology for groundwater contaminant plume treatment at the FEMP is pump and treat to remediate the plume and to prevent further off-site migration.

Competing technologies that can be designed to prevent off-site contaminant migration include: permeable reactive barriers (with iron, apatite, microorganisms, sodium dithionite), and impermeable barriers (i.e., slurry wall). These technologies, however, are typically limited in depth to less than 40 feet.

Competing technologies that can be used to create a hydrologic barrier include: horizontal wells, and trenches. Trenches are limited in their depth of installation.

MERR Technology can be used for much deeper applications than trenching and permeable barriers. Horizontal wells simply offer another geometry for re-injection systems. Impermeable barriers do not address active aquifer remediation as they are passive systems.

Technology Applicability

Re-injection systems are applicable to aquifers with sufficient permeability, homogeneity, and extent (e.g., thickness, continuity, yield) to support groundwater flushing. Re-injection systems using various treatment agents (groundwater, air, steam, bionutrients, chemical oxidants, etc.) and various well configurations may be designed to enable treatment of a wide variety of contaminants. Potential geochemical changes around the injection wells are dependent on aquifer conditions, quality of treated water delivered, and treatment agent delivered. Geochemical changes may result in plugging of the well or the surrounding matrix. Routine maintenance is required to maintain injection-well efficiency.

Injection wells are more likely to fail than typical water producing wells because of plugging due to water-chemistry changes, air entrapment, and particulates (sand, clay, silt) pumped into the well. Several factors to be considered in the general design of injection wells are described in Appendix C. Designs should:

- facilitate later modifications if necessary, such as routine maintenance of the screen area for potential iron encrustation;
- reduce the possibility that air bubbles will be injected in the well and pushed out into the aquifer (this may happen if the injectate is allowed to cascade down the well);
- allow for monitoring of sand content in the injectate (as little as 1 mg/L can clog wells over time); and
- evaluate/consider if larger diameter injection wells will incur less maintenance costs than smaller diameter wells.

Patents/Commercialization/Sponsor

Re-injection systems have been widely used for petroleum recovery, solution mining, recharge to minimize salt water intrusion in coastal areas, and waste disposal. Commercial vendors are readily available for design and installation of such systems.

The MERR demonstration at the FEMP was sponsored by the DOE's Office of Science and Technology Subsurface Contaminants Focus Area.

SECTION 5

COST

Methodology

One of the goals of the demonstration was to obtain cost information on operation and maintenance of the re-injection system. Of concern was the possibility that the wells would undergo frequent and severe plugging, leading to excessive maintenance costs. Costs for the first year of operation were lower than anticipated due to less plugging. Cost information collected during the one-year demonstration was used to conduct a life-cycle cost analysis for a re-injection system.

Two remediation scenarios were considered.

- Scenario-1 includes re-injection. Active remediation in this scenario would end in the year 2008.
- Scenario-2 does not include re-injection. Active remediation in this scenario would end in the year 2015.

All costs are given in FY00 dollars. Costs were discounted using a rate of 5.02 percent based on the U.S. Federal Reserve Discount Rate Forecast Rate found at the Financial Forecast Center (<http://www.forecast.org/disc.htm>) in January 2000. Cost values were entered into an Excel Spreadsheet, and the Excel Spreadsheet Net Present Value (NPV) function was used to calculate the net present value.

Cost Analysis

Scenario-1 is targeted toward a 10-year remediation schedule based on a groundwater model scenario that includes the demonstration injection wells and additional injection wells to be installed (Appendix B). Costing under Scenario-1 includes:

- construction costs for additional injection wells planned for the South Field,
- operation and maintenance of all injection wells, and
- monthly sampling of the treated groundwater being used for re-injection.

Table 3 presents the annual costs for Scenario-1 indicating active remediation scheduled for completion in the year 2008. Costs for the demonstration project, which occurred at the beginning of the modeled 10-year period and which total \$3.521 M, are not included in Table 3. Hence, only nine years of costs are shown. The total cost for this Scenario (in FY00 dollars) is estimated to be \$67,309,890.00.

Table 3. Annual costs for remediation cost scenario 1, re-injection with pump & treat

Year		FY00 Dollars
FY2000	Initial Period	8,715,784
FY2001	Period 1	9,046,878
FY2002	Period 2	10,167,257
FY2003	Period 3	13,503,757
FY2004	Period 4	9,289,452
FY2005	Period 5	15,146,449
FY2006	Period 6	8,820,100
FY2007	Period 7	4,868,906
FY2008	Period 8	4,378,406
Discount Rate		5.02%
Net Present Value		67,309,890

Scenario-2 looked at remediation costs using a pump-and-treat remedy that does not include re-injection. This aquifer remedy is estimated to take 17 years. Annual costs for Scenario-2 are presented in Table 4. Costs for the demonstration project, which occurred at the beginning of the modeled 17-year period and which

totaled \$3.521 M, are not included in Table 4. Hence, only sixteen years of costs are shown. Costs, up until the year 2008, are currently budgeted for baseline costs, minus the costs associated with the use of re-injection. The total cost (in FY00 dollars) for this scenario is estimated to be \$81,616,208.00.

Table 4. Annual costs for remediation cost scenario 2, pump & treat, no re-injection

Year		FY00 Dollars
FY2000	Initial Period	7,756,759
FY2001	Period 1	8,671,268
FY2002	Period 2	9,728,911
FY2003	Period 3	11,252,735
FY2004	Period 4	8,884,210
FY2005	Period 5	14,841,208
FY2006	Period 6	8,597,293
FY2007	Period 7	4,868,905
FY2008	Period 8	4,864,652
FY2009	Period 9	4,864,652
FY2010	Period 10	4,864,652
FY2011	Period 11	4,864,652
FY2012	Period 12	4,864,652
FY2013	Period 13	4,864,652
FY2014	Period 14	4,864,652
FY2015	Period 15	4,864,652
Discount Rate		5.02%
Net Present Value		\$81,616,208

Subtracting the costs for Scenario 1 (\$67,309,890.00) from the costs for Scenario 2 (\$81,616,208.00) results in a difference of \$14,306,318.00. This is the predicted cost saving (in FY00 dollars) that should be realized through the use of re-injection to accelerate the aquifer remedy.

Three different well-casing diameters were used for the demonstration injection wells to evaluate an optimal diameter. Table 5 provides the costs for installing various well sizes. It costs approximately twice as much to install a 16-inch diameter well as it does to install an 8-inch diameter well. Based on cost information collected during the demonstration, it costs approximately \$14,000.00 per treatment to address plugging in injection wells, regardless of well diameter. The difference in installation cost for an 8-inch diameter vs. a 16-inch diameter injection well is approximately equal to the cost of 2.2 plugging treatments (\$30,800.00). Assuming that well diameter is a primary factor for well maintenance (the 8-inch well required treatment 2-4 times as often as the 16-inch well). It appears to be more cost effective to install a 16-inch diameter rather than 8-inch diameter injection wells.

Table 5. Well installation costs

Diameter of well	8 inches	12 inches	16 inches
Diameter of boring	12 inches	20 inches	24 inches
Length (ft)	100	100	100
Cost/foot	\$285.00	\$450.00	\$533.00
Stainless steel screen/sump/riser/flange	\$1,400.00	\$4,789.00	\$6,981.00
Installation costs	\$29,900.00	\$49,789.00	\$60,281.00

Cost Conclusions

Assuming that groundwater re-injection accelerates aquifer remediation by 7 years as predicted by the model, the aquifer remediation project could realize a potential (net present value) cost savings of approximately \$14.3 million dollars. The estimated total project cost (net present value) for using groundwater re-injection and completing active remediation in the year 2008 is \$67.3 million dollars. The estimated total project cost (net present value) for not using groundwater re-injection and completing active remediation in the year 2015 is \$81.6 million dollars.

SECTION 6 REGULATORY AND POLICY ISSUES

Regulatory Considerations

Permit requirements are site specific and depend on state/federal requirements. An Underground Injection Control Permit may be required. Adherence to regulations such as CERCLA and a National Environmental Protection Act analysis at federal facilities may be required.

Concurrence from Ohio EPA (OEPA) to proceed with the MERR demonstration was obtained, but no underground injection control permit was required, because the demonstration was conducted as part of an active Comprehensive Environmental Recovery, Compensation, and Liability Act (CERCLA) cleanup. In accordance with OEPA re-injection guideline "5X26 Aquifer Remediation Projects" (OEPA 1997), treated groundwater must be analyzed monthly prior to and during the demonstration. The sampling results furnished in monthly reports to the OEPA included:

- analysis of injectate;
- volume and rate of injection;
- description of any well maintenance and rehabilitation procedures conducted; and
- results of groundwater monitoring.

Additional quarterly reporting provided to the OEPA as part of the Integrated Environmental Monitoring Plan included:

- assessment of demonstration performance; and
- water-table map and capture-zone interpretation.

Permit requirements are site specific and depend on state/federal requirements. An Underground Injection Control Permit may be required. Adherence to regulations such as CERCLA and a National Environmental Protection Act analysis at federal facilities may be required.

Safety, Risks, Benefits, and Community Reaction

Potential worker safety risks include those associated with standard construction operations as well as those associated with work at a hazardous waste site.

All field personnel must be 40-h Occupational Safety and Health Administration trained as required in 29 Code of Federal Regulations (CFR) 1910.120 for hazardous waste operations.

Engineering control safeguarded against the overflow of injection water onto the ground surface should the well plug rapidly.

Installation and operation of injection wells do not produce routine release of contaminants.

The use of sodium hypochlorite to treat plugging in the injection wells required special safety procedures.

Well installation and development generates excess soil cuttings and purge water. However, during re-injection, few secondary wastes other than ion exchange resins in the treatment facility, are generated.

There has been strong community and other stakeholder support for this demonstration since its inception.

SECTION 7

LESSONS LEARNED

Implementation Considerations

To ensure the implementability of the MERR technology, two single-well re-injection tests were conducted to obtain preliminary operational information.

- The first test consisted of untreated groundwater, containing <20 ug/L of total uranium, injected at a constant rate of 300 gpm for 72-hours. After ~10 hours, water levels began to rise, indicating plugging of the formation and/or well screen. Test results confirmed the presence of iron precipitation and iron bacteria in the well screen. Sampling and geochemical modeling conducted after the test indicated that injecting treated effluent would not result in well-screen plugging.
- The second test consisted of injecting treated groundwater at a constant rate of 200 gpm for 114 hours. These results confirmed that treated groundwater could be injected into the aquifer with minimal plugging of well screens.
- Results of these tests indicated that re-injection was feasible at the FEMP. However, long-term dependability and maintenance costs remained unproven.

Prior to the demonstration, several different modeling scenarios, varying the number and location of extraction wells and adding injection wells, were conducted and presented in the Baseline Remedial Strategy Report (Appendix B). The selected modeling scenario predicted groundwater remediation in 10 years, using extraction and injection wells as placed for the demonstration.

During the demonstration, a series of additional operational measures were taken to keep the injectate uranium concentrations equal to or below 10 µg/L. These additional measures include:

- new procedures to successfully regenerate AWWT Expansion Facility ion-exchange vessels;
- routine monitoring of ion-exchange resin loading with projections as to when a given vessel must be regenerated;
- implementation of a routine regeneration schedule;
- changes to valving lineups to provide redundant isolation of regeneration water (eluate) containing high concentrations of uranium from the treated water routed to the re-injection system; and

One of the most critical issues in design and operation of a re-injection system is that of well plugging, which is the result of a decrease in porosity within the gravel pack, the formation surrounding the well screen, and/or a decrease in the openings of the well screen itself. Under such conditions and given a constant injection rate, the water level in the well will rise to compensate for the greater pressure needed to move the same volume of water through a smaller opening. When plugging occurs within a well, the well needs to be treated to restore the efficiency of the well. If numerous treatments are needed for maintaining the operational efficiency of the well, then the treatment costs could negate the benefits realized by the use of re-injection.

Technology Limitations and Needs for Future Development

Specific to the FEMP demonstration site, future recommendations/concerns for use of MERR include:

- sampling of the injectate, in addition to the monthly FRL sampling, should continue for pH, Eh, and TSS. The TSS samples should be composite samples;
- monitoring for Eh and pH in the aquifer, in the area of re-injection, should continue;
- a direct-push sampling program along the southern FEMP property boundary should continue;

- the injection well treatment strategy should continue to be followed to watch for signs of plugging within the injection wells; and
- the monthly injectable grab sample should be changed to one daily composite sample.

Technology Selection Considerations

Plugging in the injection wells was less of an issue than anticipated at the start of the demonstration. No indication of residual plugging was noticed during the year-long demonstration. However, some degree of residual plugging is anticipated over a long period of time. The impact that residual plugging might have on future operational costs remains uncertain, but is expected to be manageable.

APPENDIX A

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APPENDIX B

Baseline Remedial Strategy Modeling

Modeling Overview

Model simulations were conducted to:

- develop potential cost-effective approaches for shortening the time for the Great Miami Aquifer restoration,
- evaluate the effectiveness of groundwater enhancement technologies.

Four, time-based, remedial scenarios representing a range of aquifer cleanup times (7.5, 10, 15 and 25 years) were simulated to determine the required system components, i.e., number of extraction and injection wells and required groundwater treatment capacity. Modeling was conducted using the Sandia Waste Isolation Flow and Transport (SWIFT) model. The SWIFT code is a fully coupled, transient, 3-dimensional finite-difference model for groundwater flow through both porous and fractured media. Numerous adjustments to the number and location of extraction and injection wells were evaluated during modeling of the four scenarios.

General assumptions incorporated in the groundwater transport modeling included the following.

- Target Plumes – Target plumes were conservatively based on the maximum uranium concentrations measured in each groundwater monitoring well.
- Surface Remediation Schedule – Source operable-unit remediation schedules in the FEMP's Ten Year Plan were used to develop remediation scenarios that incorporated earlier well installation in areas where soil remediation is scheduled to take place first.
- Treatment Capacity Schedule – Treatment capacities in the first and second years (1996 and 1997) were assumed to be 400 and 850 gpm respectively, with an expanded total treatment capacity of 2000 gpm available in the third year (1998) and additional capacity added in 250 gpm increments as needed.
- Source of Injection Water – Only treated groundwater can be injected to prevent plugging.
- Geochemical Conditions – The mass of uranium and other contaminants of interest available for desorption are concentration dependent and variable (decreasing) over time (DOE 1997).
 - A range of varying uranium adsorption/desorption ratios (1.78 to 17.8 L/kg) were used.
 - The proposed adsorption/desorption ratios predicted lower mobility of uranium possibly requiring additional extraction wells to be an effective removal system.
 - In areas where initial uranium contamination is <200 ppb the presence of chemisorbed and precipitated uranium may result in shorter cleanup times because less uranium will be released from an aquifer matrix.
- Off-Property Access – It was assumed that access to all off-property wells was available without constraint.
- Funding – Sufficient funding was assumed for each potential remediation scenario.

During the modeling simulations, sensitivity analysis was conducted on all natural factors (hydraulic characteristics, geochemical processes, and injection-well performance). Because the uncertainties associated with the human factors cannot be easily quantified (well design and installation, remediation schedules, system operation and maintenance, and funding), uncertainty analyses focused on the natural factors only. The most critical natural factors affecting cleanup time were determined to be geochemical parameters such as mass transfer of uranium.

Selection of the preferred re-injection strategy was based upon comparison of the simulations to the performance goals, which include:

- minimize hydraulic impacts;
- maximize the mass-removal efficiency;
- minimize impacts to wastewater treatment operations;
- maximize the usefulness of monitoring data;
- minimize the system downtime; and
- minimize the overall remediation cost.

Based on the overall costs (Figure B-1) and risk/uncertainty evaluation, the 10-year scenario was selected as the optimum baseline enhancement based on:

- overall cost (Figure B-1);
- capital cost for well installation is distributed over 7 years;
- piping network complexities due to the additional extraction wells are considered manageable; and
- no additional treatment capacity beyond the planned AWWT facility expansion was necessary.

The optimum baseline enhancement did have higher risk and uncertainty than the other scenarios due to its reliance on surface access after soil remediation.

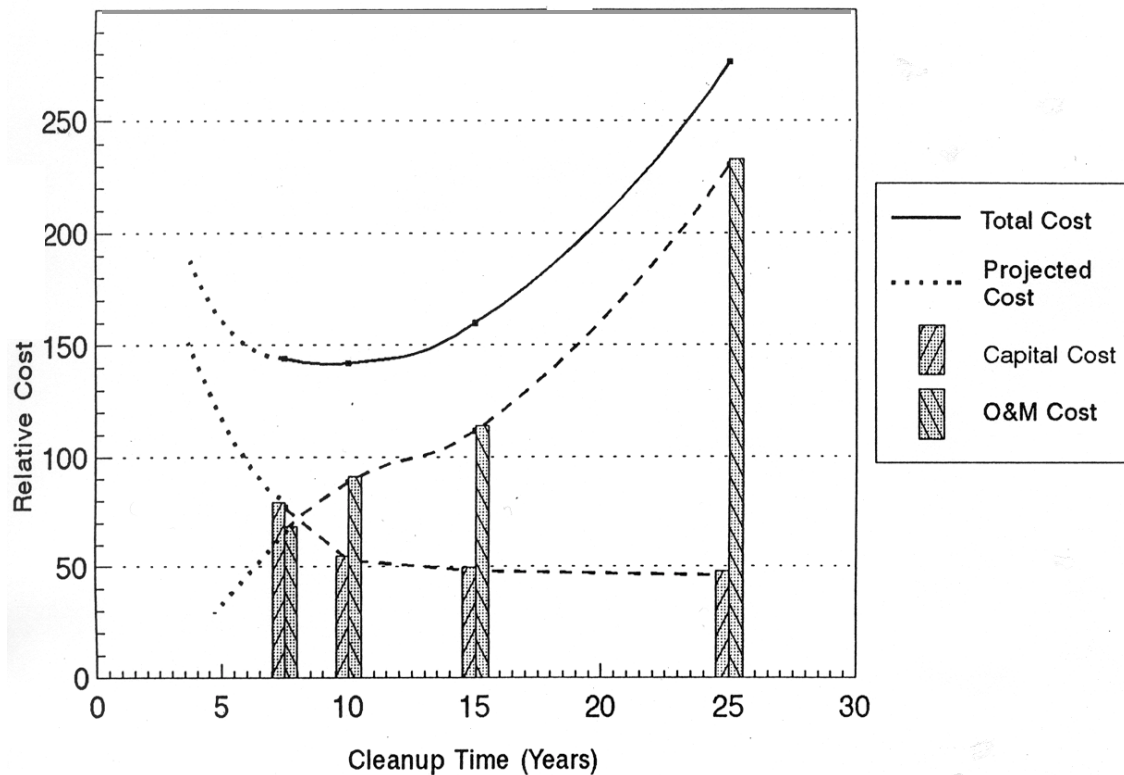


Figure B-1. Conceptual cost comparison.

The selected baseline strategy was then finalized by considering three implementation issues: funding profiles, off-property access constraints, and current plume configuration. Concurrently, the plume was further delineated by collection and analyses of soil samples using Geoprobe™ techniques. Additional modeling simulations of the plume as defined by the Geoprobe™ information and specific to the demonstration module were conducted to:

- evaluate the potential for downward plume expansion at the injection locations;
- find possible solutions for minimizing further downward plume expansion, if necessary;
- evaluate the potential of further cross-fenceline plume migration;
- find possible solutions for minimizing further cross-fenceline plume migration, if necessary;
- provide information (i.e., well-screen depth) required to continue the on-going injection well installation; and
- provide information (e.g., well locations) for the on-going design efforts for the Phase I South Field Module and South Plume Optimization Module.

Results of this modeling indicated:

- installation of the demonstration injection well at a depth range between 509 and 490 ft above mean sea level with the top of the injection well screen at ~19 ft bgs;
- add extraction well 22, which will significantly reduce cross-fenceline plume migration, to the Phase I South Field Module; and
- minimize the lag-time between start-up of the demonstration wells, the South Plume Optimization Module, and the expanded South Field Phase I Module.

In the absence of extraction wells along the eastern edge of the off-property uranium plume, the baseline strategy will, in effect, be relying on a controlled natural attenuation approach to address the expanding portion of the plume. This extent, based on modeling simulations, will still reside within (and therefore be controlled by) the hydraulic capture zone created by the existing South Plume recovery wells. However, most importantly, these modeling results show that scenarios with the addition of groundwater injection will provide better overall performance than scenarios without.

Demonstration Impacts Based on Modeling Results

The model prediction for the 10-year aquifer cleanup strategy illustrates the interpreted capture zone and anticipated flow patterns within the expected capture zone over the life of the remedy under steady-state conditions (Figure B-2). This modeling scenario includes not only the five demonstration injection wells, but also injection wells planned for the South Field Area.

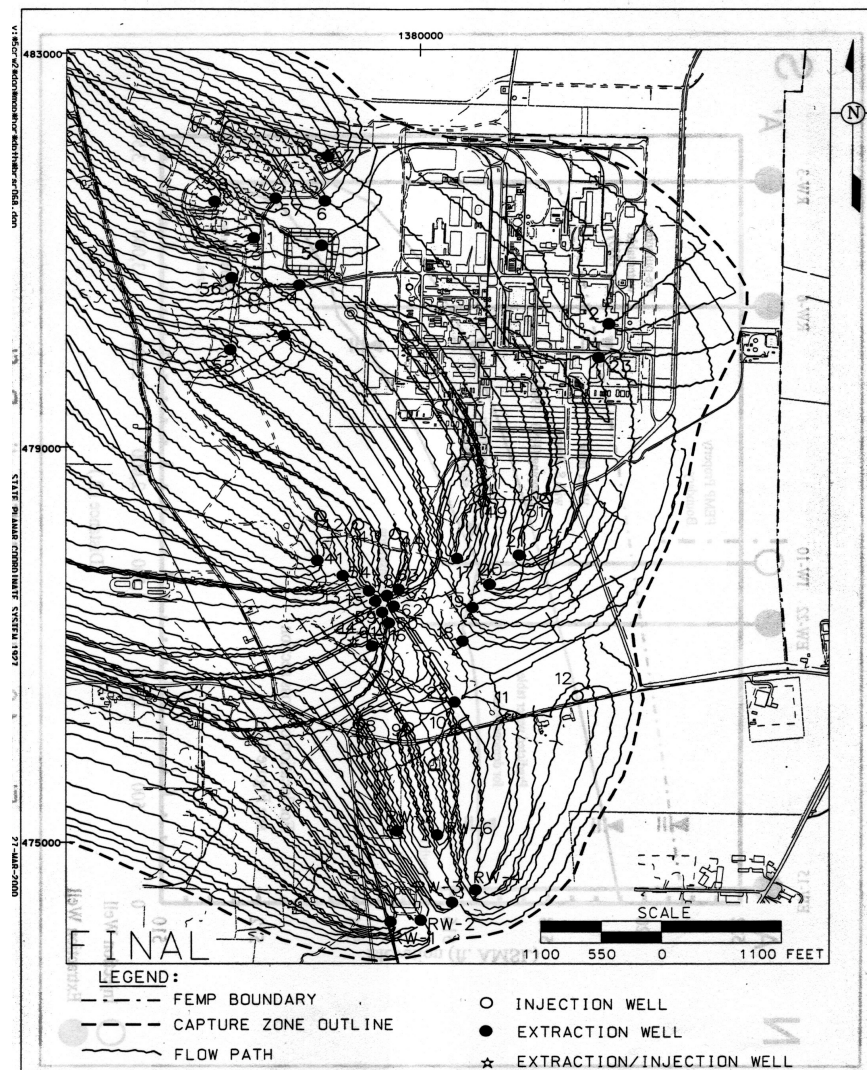


Figure B-2. Modeled capture zone for the 10-year remediation strategy.

Particles were seeded in the model blocks containing the pumping wells. The model was then run backwards in time and the particles were allowed to track backwards, as dictated by the forces of flow exerted within the model, to determine where the particles came from, resulting in a time-dependent capture zone for each pumping well.

The particle tracks illustrate that pumping in the South Field coupled with pumping in the South Plume would create a stagnation zone between the two pumping systems. Contamination within this stagnation zone will essentially be held in place. This stagnation zone was predicted to be located in the vicinity of the southern FEMP property boundary. This stagnation zone would also serve as a hydraulic barrier to prevent further contaminant flow across the property boundary.

The injection wells were positioned within the stagnation zone created between the South Field and South Plume pumping systems. The groundwater model predicted that re-injection in this stagnation zone would:

- help flush uranium contamination out of the stagnation zone and toward the pumping wells in the South Plume; and
- slightly raise water levels within the stagnation zone.

The "pre-pumping water table (pre 1993)" profile shown in Figure B-3 represents actual average elevation

data collected prior to the start of pumping in the South Plume. This surface indicates that under no-pumping conditions flow is normally to the south. The surface labeled "water table-pumping (1993 to 1998)" is an average of actual field data collected during the time period when only the South Plume extraction wells were operating. The surface labeled "predicted water table for demonstration," is the modeled steady-state water table profile predicted for the time period when injection and pumping in the South Field is superimposed with the South Plume.

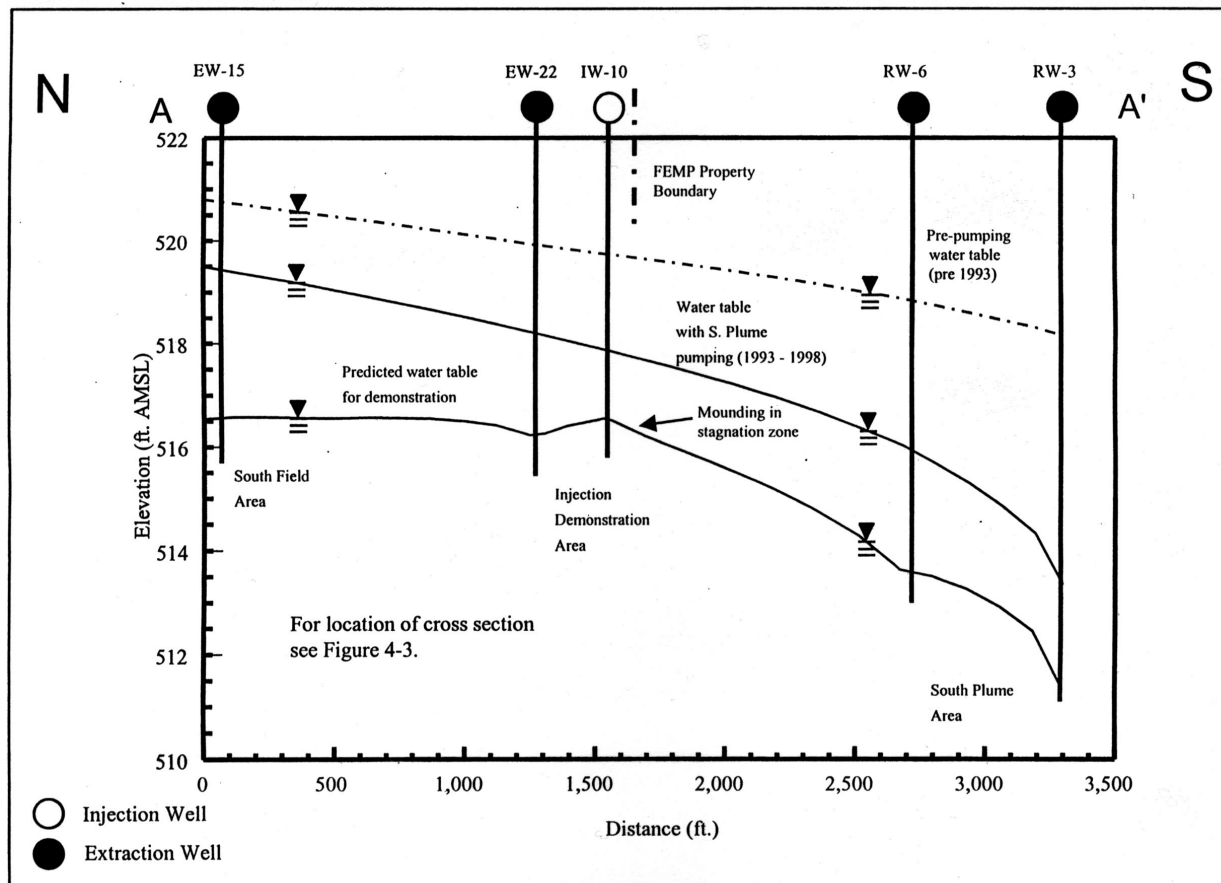


Figure B-3. Water-table elevation profile.

As shown in Figure B-3, the combined effect of both pumping and injection is a predicted overall lowering of the water table. North of the demonstration, the predicted drop in water level was 4 to 6 feet below the 1993 pre-pumping levels. South of the injection test area the predicted drop was 4 to 4.5 feet below the 1993 pre-pumping levels. In the area of re-injection itself, a drop of approximately 3 feet was predicted. However, re-injection was expected to cause water levels adjacent to the injection wells to rise approximately 0.5 feet. Raising the water level in the re-injection area was expected to result in increased flushing and a reduction in the size of the stagnation zone.

Finally, it was also anticipated that re-injecting groundwater north of the South Plume Extraction wells would supply water to the South Plume Extraction wells and help alleviate the drawdown of the water table surface in the area of the South Plume wells. Reducing the amount of drawdown in this area would reduce the impact that pumping in the South Plume Wells has on the Paddy's Run Roadside Plume, which is located just south of the South Plume Recovery Wells.

APPENDIX C

Demonstration Plan Details

The general design of the injection-well screens was based on:

- use of continuous wire-wrapped screen;
- sieve analysis of core samples to select screen slot-size to maximize the open area of the screen;
- an average screen exit velocity of 0.05 ft/sec or less;
- use of natural well completions unless velocity calculations indicate a screen exit velocity greater than 0.05 ft/sec, then use of a filter pack;
- setting the top of the well screen so that it would remain below the surrounding water table during aquifer injection;
- restricting injection to areas of the aquifer where total iron concentration is below 0.15 ppm;
- selecting screen length based on the thickness and depth of the total uranium plume (20 ug/L), spinner tool data collected from the second single-well injection test, and total iron concentrations.

Well completion information is provided in Table C-1.

Table C-1. Well completions

Well ID	Well Diameter	Type of Filter Pack	Screen Length	Screen Slot Size
22107 (IW-8)	8-inch	Sand	15 ft	.060 inches
22108 (IW-9)	12-inch	Sand	15 ft	.060 inches
22109 (IW-10)	16-inch	Natural	15 ft	.040 inches
22240 (IW-11)	16-inch	Sand	19.6 ft	.060 inches
22111 (IW-12)	16-inch	Sand	15 ft	.060 inches